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"Criticality HazOp": Efficiently Evaluating Hazards of New or Revised Criticality Safety Evaluations

Prepared for the U.S. Department of Energy
Assistant Secretary for Environmental Management

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Abstract

The "Criticality HazOp" technique, as developed at Hanford's Plutonium Finishing Plant (PFP), has allowed for efficiencies enabling shortening of the time necessary to complete new or revised criticality safety evaluation reports (CSERs). For example, in the last half of 2007 at PFP, CSER revisions undergoing the "Criticality HazOp" process were completed at a higher rate than previously achievable. The efficiencies gained through use of the "Criticality HazOp" process come from the preliminary narrowing of potential scenarios for the Criticality analyst to fully evaluate in preparation of the new or revised CSER, and from the use of a systematized "Criticality HazOp" group assessment of the relevant conditions to show which few parameter/condition/deviation combinations actually require analytical effort. The "Criticality HazOp" has not only provided efficiencies of time, but has brought to criticality safety evaluation revisions the benefits of a structured hazard evaluation method and the enhanced insight that may be gained from direct involvement of a team in the process. In addition, involved personnel have gained a higher degree of confidence and understanding of the resulting CSER product.

The "Criticality HazOp" Process

DOE-STD-3007-2007, *Guidelines for preparing Criticality Safety Evaluations at Department of Energy Nonreactor Nuclear Facilities,* requires that a disciplined method for identifying credible upset conditions be used in the development of CSERs. PFP has been using the HAZOP method for several years. The "Criticality HazOp" process that has evolved at PFP has increased the quality of CSER products while shortening the time required for their production. The "Criticality HazOp" process combines existing criticality analysis guidance with evaluation techniques adapted from standard Hazard Analysis methodology to streamline and systematize the creation of new or revised CSER products. The following subsections describe the steps of the process and the efficiencies and quality improvements gained through their use.

Define Relevant Controlled Parameters

Parameters for CSER analysis and controls normally include the following:

- Mass (M)
- Volume (V)
- Interaction (I)
- Geometry (G)
- Moderation (Mod)
- Reflection (R)
- Enrichment (E)
- Density (D)
- Concentration (C)
- Poisons (P)

Not all parameters are relevant for every criticality analysis. Some parameters may only be applicable to types of processes different from the one under consideration (e.g., "Poisons" is often considered solutions-processing-related and normally would not be considered applicable to, as an example, a waste container analysis).

The "Criticality HazOp" process begins with an assessment of the particulars of the operation to be evaluated to determine which parameters are actually relevant to the analysis, and which may be disregarded. This is normally performed cooperatively by the Criticality and Hazard analysts, before a "Criticality HazOp" meeting is called. Depending on the nature of the process being analyzed, the determination may be immediately obvious, or may require some amount of judgment on the part of the Criticality analyst to decide if a particular parameter may be disregarded or not.

Determine Potential Relevant Conditions

When the relevant parameters for the CSER have been chosen, a further narrowing of emphasis is performed when a list of pre-defined relevant conditions taken from ANSI/ANS 8.1 is evaluated for each parameter. Not every parameter will be relevant for every condition, and in evaluating the list of parameters against the list of relevant conditions, decisions as to which of the parameters will be affected can be made and recorded.

A tabular form of the lists of conditions given in ANSI/ANS 8.1 has been developed at PFP to aid in this determination, and is shown in Table 1:

Table 1: Example ANSI/ANS 8.1 Conditions Table		
Affected Parameter	**Condition**	**Relevant Or N/A?**
Variations to the equipment's primary control dimension due to:		
	Fabrication tolerances, including failure to meet specifications in fabrication.	
	Mechanical disarrangement (earthquake).	
	Chemical attack (Corrosion).	
	Thermal effect (fire).	
	Effects due to accidental pressurization.	
	Bulging.	
Excesses in the mass or volume in a batch from errors in:		
	Segregating materials of different enrichments.	
	Procedure (multiple batching or other operational error).	
	Analysis (decimal point errors, in information transmittal, or non-representative samples).	
	Maintaining uniformity of materials (precipitates, samples from one phase or two-phase system, etc.).	
	Improper labeling.	
	Loss of control of number or size of containers.	
	Equipment failure.	
Excess of mass in a non-safe geometry vessel resulting from:		
	Flow through cross connections such as vents, overflows, or chemical addition lines.	
	Accidental transfers resulting from valve leakage.	
	Unauthorized piping changes.	
Changes in geometry resulting from:		
	Leakage (from corrosion).	
	Mechanical failure (e.g., bursting of a container or mold breakage).	
	Mechanical compacting (accidental crushing of shapes in a hydraulic lift or fire).	
	Natural phenomena up to the DSA considered seismic event.	
Changes in reflection from:		
	Flooding	
	Soaking of insulation.	
	Filling of a jacket space by leakage.	
	Approach of personnel.	
	Addition of shielding.	
	Accidental movement relative to reflectors such as glovebox or hood walls (from dunnage failure).	
	Loss of absorber (e.g., by corrosion of an outer casing of absorber).	
Changes in concentration from:		
	Recycling or refluxing (from chemical makeup errors involving loss of salting strength, or from flow failure, flooding, or other process failure).	
	Precipitation.	
	Accumulation.	
	An increase in the density of fissionable material.	
	Evaporation.	
	Dilution.	
	Other process upsets.	

(cont.)

Table 1: Example ANSI/ANS 8.1 Conditions Table		
Affected Parameter	**Condition**	**Relevant Or N/A?**
Increased interaction from:		
	Collapse of shelving or spacers.	
	Introduction of reflector (e.g., personnel).	
	Material in transit.	
	Excessive additions to an array (including possible multiple batching at the center of the array).	
	Loss of moderator and absorber between units.	
	Changes in relative position of units by water flooding and floating of units (with possible relevant changes in reflection of individual units).	
	Spacing errors, including improper placing of units.	
Changes in moderation from:		
	In-leakage.	
	Inaccuracies in instruments or chemical analyses.	
	Absorption by hygroscopic material.	
	Flooding, spraying, or otherwise supplying units or groups of units with water, oil, snow (i.e., low-density water), cardboard, wood, or other moderating material.	
	Condensation.	
	Inadequate drying (as by loss of temperature control from instrument malfunction).	
	Introducing air bubbles between rows of fuel assemblies in a storage basin.	
	Firefighting activity.	
	Evaporation or displacement of moderator.	
	Precipitation.	
	Dilution.	
	Deliquescence.	
	No drains to prevent excessive solution height.	
	Accidental use of moderating liquid in place of non-moderating liquid (as water vs. carbon tetrachloride)	
Changes in absorbers from:		
	Loss of solid absorber by corrosion or by leaching.	
	Redistribution of absorber and fissionable material by precipitation of one but not the other from a solution.	
	Redistribution of solid absorber within a matrix of moderator or solution by clumping.	
	Failure to add the intended amount of absorber to a solution or failure to add it with the intended distribution.	
	Failure of analytical techniques to yield correct amounts of concentrations.	
Natural Phenomena and Other		
	Fire Fighting.	
	Flooding.	
	Earthquake.	
	[Others as needed]	

For each condition relevant to the analysis at hand, the parameters which may affect or be affected by that condition are noted on the table. This provides the base set of items to be evaluated in the "Criticality HazOp" meeting. It is not necessary to carry the whole table into the "Criticality HazOp" meeting - for clarity and efficiency, only those sections of the table showing evaluated, relevant conditions are included for use. Table 2 gives an example of a table completed to this point, taken from a CSER evaluating storage of nuclear material containers:

Table 2: Example Partial ANSI/ANS 8.1 Hazards Assessment Parameter List		
Affected Parameter	**Condition**	**Relevant Or N/A?**
Equipment dimensional variation due to:		
V	Fabrication tolerances, including failure to meet specifications in fabrication.	
I / G	Mechanical disarrangement (earthquake).	
Excesses in the mass or volume from errors in:		
M	Segregating materials of different enrichments	
M / V	Overbatching	
M / V / I / G	Loss of control of number or size of containers	
M	Maintaining uniformity of materials	
Excess of mass in a non-safe-geometry vessel resulting from:		
G	Cross connections	
G	Unauthorized piping changes	
G	Accidental transfers resulting from valve leakage	
Changes in geometry resulting from		
G	Spilling or leakage	
I / G	Mechanical compacting	
G	Natural phenomena	
Changes in reflection from		
M	Flooding	
I	Addition of shielding (dose reduction campaign)	
Changes in concentration from		
M / V / I	Precipitation	
M / V / I	Accumulation	
M / V / I	Evaporation	
Increased interaction from		
G	Collapse of shelving or spacers	
I	Material in transit	
I / G	Spacing error	
Changes in moderation from		
--	Condensation	
--	Evaporation	
--	Draining	
Natural Phenomena and Other		
M / V / I / G	Fire Fighting	
M / V / I / G	Flooding	
M / V / I / G	Earthquake	

Convene "Criticality HazOp" Meeting

A "Criticality HazOp" meeting should include personnel from an array of disciplines: the Criticality and Hazard analysts; potentially other criticality engineers; operations; safeguards; and other affected groups at the facility.

The meeting proceeds much like a normal hazards evaluation meeting, with an initial briefing from the Criticality analyst on the operation to be evaluated, and the equipment and locations that the hazard evaluation team must be concerned with. This allows everyone to begin on the same footing. A list of assumptions may be generated from discussion during this portion of the meeting.

The prepared ANSI/ANS 8.1 list is distributed, and each item is discussed by the team. Each affected parameter is considered: first, the team determines if the given parameter for a particular condition is actually affected and belongs on the list; second, the team discusses each parameter in light of the particular situation (i.e., equipment, process, location, etc.) related to the operation to be evaluated to determine if that particular parameter is actually relevant in the current case. Those parameters judged to be relevant are the ones which will be evaluated in the hazard evaluation portion of the meeting. Table 3 gives an example (from the same "Criticality HazOp" session as above) of a completed table, indicating which parameters for a particular condition are judged relevant ("X"), and which are not (N/A).

Table 3: Example Completed ANSI/ANS 8.1 Hazards Assessment Parameter List

Affected Parameter	Condition	Relevant Or N/A?
Equipment dimensional variation due to:		
V	Fabrication tolerances, including failure to meet specifications in fabrication.	N/A
I / G	Mechanical disarrangement (earthquake).	N/A
Excesses in the mass or volume from errors in:		
M	Segregating materials of different enrichments	N/A
M / V	Overbatching	N/A
M / V / I / G	Loss of control of number or size of containers	N/A
M	Maintaining uniformity of materials	N/A
(cont.)		
Excess of mass in a non-safe-geometry vessel resulting from:		
G	Cross connections	N/A
G	Unauthorized piping changes	N/A
G	Accidental transfers resulting from valve leakage	N/A
Changes in geometry resulting from		
G	Spilling or leakage	N/A
I / G	Mechanical compacting	N/A
G	Natural phenomena	**X**
Changes in reflection from		
M	Flooding	**X**
I	Addition of shielding (dose reduction campaign)	**X**
Changes in concentration from		
M / V / I	Precipitation	N/A
M / V / I	Accumulation	N/A
M / V / I	Evaporation	N/A
Increased interaction from		
G	Collapse of shelving or spacers	N/A
I	Material in transit	**X**
I / G	Spacing error	**X**
Changes in moderation from		
--	Condensation	N/A
--	Evaporation	N/A
--	Draining	N/A
Natural Phenomena and Other		
M / V / I / G	Fire Fighting	**X**
M / V / I / G	Flooding	**X**
M / V / I / G	Earthquake	**X**

When the relevant parameters have been selected and agreed upon, each is assessed for their potential criticality hazard using a modified "HazOp" technique. Each relevant parameter is brought up and has a "deviation" applied to it. The resulting conditions are discussed and assessed to determine the affect that the deviation may have on the parameter, and whether that parameter deviation may pose any new or changed criticality hazards. Similar to a normal "HazOp," a deviation guide (see Table 4) is normally used to systematize the assessment, and to spark discussions and new ideas among the participants. Frequency rankings are assigned using standardized ranges.

Results are recorded in a table (see Table 5), which will serve as the end product of the "Criticality HazOp," and is the process's input to the Criticality analyst. It should be noted that the "Notes" column, which records discussions and facts brought up during the "Criticality HazOp" meeting, can prove extremely important as a source of captured information and assumptions to be used in the analyst's work.

Table 4: Hazards and Operability Deviation Guide

Process Parameter	Guide Words						
	No, Not, None	Less, Low, Short	More, High, Long	Part Of	As Well As, Also	Other Than, Where Else	Reverse
Flow	No flow	Low rate, low total	High rate, high total	Misdirection, missing ingredient	Misdirection, contamination, impurities	Wrong material	Backflow
Pressure	Open to atmosphere	Low pressure	High pressure				Vacuum
Temperature	Freezing	Low temperature	High temperature				Auto-refrigeration
Level	Empty	Low level	High level	Low interface	High interface		
Confinement	No confinement	Degraded confinement				Bypass pathway	
Time procedure	Skipped or missing step	Too short, too little	Too long, too much	Action(s) skipped	Extra action(s) (shortcuts)	Wrong action	Out of order, opposite
Speed	Stopped	Too slow	Too fast	Out of sync		Web or belt break	Backward
Composition/ Concentration	Missing ingredient	Less ingredient/ Low concentration	More ingredient/ high concentration	Missing ingredient	Contaminant/ additional ingredient	Wrong ingredient	
pH		Low pH	High ph		Additional acid, additional base	Wrong acid, wrong base	
Viscosity		Low viscosity	High viscosity				
Voltage	No voltage	Voltage low	Voltage high	Wrong waveform	Interference voltage	Wrong frequency, AC instead of DC DC instead of AC	Wrong polarity
Current	No current	Current low	Current high			Current fluctuating	Wrong polarity
Static			Static charge				
Agitation	No mixing	Poor mixing	Excessive mixing	Mixing interruption	Foaming		Phase separation
Reaction	No reaction	Slow reaction	Runaway reaction	Partial reaction	Side reaction	Wrong reaction	Decomposition
Structural integrity	Structural failure	Less integrity	More integrity				
Shielding		Less shielding	More shielding				
Special	Utility failure	External leak	External rupture	Tube leak	Tube rupture	Startup, shutdown, maintenance	

Table 5: Example CSER Hazards Assessment Table							
Item No.	**Parameter**	**Deviation**	**Causes**	**Consequences**	**Barriers**	**Freq.**	**Notes**
1	Geometry	Less favorable	Seismic event	N/A	--	U	Rearrangement of close-packed array reduces interaction and actually gives a more favorable geometry.
2	Reflection	Increased	Flooding Array	Increased reactivity of Array	None	A	This is an expected upset, and the case of a fully-flooded Array will be analyzed in this CSER.
3	Reflection	Decreased	Flooded individual container	N/A	--	U or EU	If the loaded container is flooded external to the secondary containment vessel, it serves to further isolate the contained material from the rest of the Array.
4	Reflection	Increased	Addition of Pb shielding	Possible increase in reactivity	None	A	Shielding bounded by full flooding. Pb reflects fast neutrons, but very few neutrons leaving the containers are anything other than thermal in energy level.
5	Reflection	Decreased	Addition of borated polyethylene shielding	Decrease in reactivity	None	A	--
6	Interaction	Increased	Material in transit (in wagons, hand-carried, etc.) approaches Array	Increased reactivity of system	Administrative movement controls Implemented physical controls Procedures & Training	A	--
7	Interaction	Increased	Spacing errors	Increased reactivity of system	Administrative movement controls Implemented physical controls Procedures & Training	A	Containers on wheeled dollies may interact with wagons. Items to cover for spacing can include containers, wagons, 200-g waste drums, SWBs, etc.

Table 5: Example CSER Hazards Assessment Table							
Item No.	**Parameter**	**Deviation**	**Causes**	**Consequences**	**Barriers**	**Freq.**	**Notes**
8	Geometry	Less favorable	Fire-fighting action rearranges containers in array	Increased reactivity of system	None	A	--
9	Reflection / Moderation	Increased	Fire-fighting flooding	Increased reactivity of system	None	A	--
10	Reflection / Moderation	Increased	Flooding from natural causes	Increased reactivity of system	None	A	--
11	Geometry	Less favorable	Seismic event	N/A	--	U	Rearrangement of close-packed array reduces interaction and actually gives a more favorable geometry.
12	Interaction	Increased	Seismic event	Increased reactivity of system	Implemented physical controls	A	--
13	Interaction	Increased	Non-compliant container (i.e., incorrectly assembled with internal structures missing)	N/A	Procedures & Training	Single: A Array: EU	The "heat shields" that fit in the top of the container have been left off before, briefly, before drum lids were sealed. If one is left off, it creates a slightly-less shielded pathway through the top of the container for interaction. While it is just possible that this might happen with a single container, it is very unlikely to occur in an entire Array worth of containers.

Apply "Criticality HazOp" Results to Analysis

In reviewing the "Criticality HazOp" results, the analyst will normally concentrate on analyzing those conditions which were judged during the meeting to have a frequency of "Anticipated". These conditions will normally prove to be bounding for the other conditions assessed in the table. Conditions with assigned frequencies of "Unlikely" or "Extremely Unlikely" may be used for contingency/upset analyses. The CSER analyses are then performed using normal, approved methods.

Publish "Criticality HazOp" Results

The report for the "Criticality HazOp" is normally presented as an Appendix to the CSER. This report is structured as a condensed Hazard Evaluation document, and normally contains the following sections:

- **Introduction** – Provides the basic information regarding the CSER being revised, and the scope of the "Criticality HazOp."
- **Hazard Assessment and Scope** – Provides the list of relevant parameters (and perhaps a rationale for including or excluding certain parameters), and the completed ANSI/ANS 8.1 table as shown in Table 3 above.
- **Hazards Assessment** – Provides the attendance list for the "Criticality HazOp" meeting, an explanation of the rationale for and specifics of the hazard evaluation, and the results of the hazards evaluation, including whether any new or increased hazards were uncovered as a result of the "Criticality HazOp."
- **Raw Hazards Assessment Table** – The completed table generated in the "Criticality HazOp" meeting, as shown in Table 5 above.

Conclusion

The "Criticality HazOp" technique, as it has evolved at PFP, has proven to be an efficient tool for quickly focusing analytical efforts in the creation or revision of CSERs. Through pre-assessing relevant parameters and conditions, and using the group-based, systematic evaluation techniques of a HazOp-type meeting, the specific analyses required to be undertaken for the particular CSER can be quickly narrowed down. This allows the Criticality Analyst to more effectively direct analytical time and expedite the completion of the CSER.